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Publication Title:

Concentration of particles in a fluid within an acoustic standing wave field

Abstract:

A device for performing the manipulation of particles suspended in a fluid, comprises a chamber forming a duct for the flow of the fluid, and an acoustic transducer (10) and a reflector (12) for establishing an acoustic standing wave field across the width of the duct the spacing between the transducer and reflector is 300 microns or less. With such a small spacing, the device is particularly effective at concentrating the particles and lower operating voltages are required

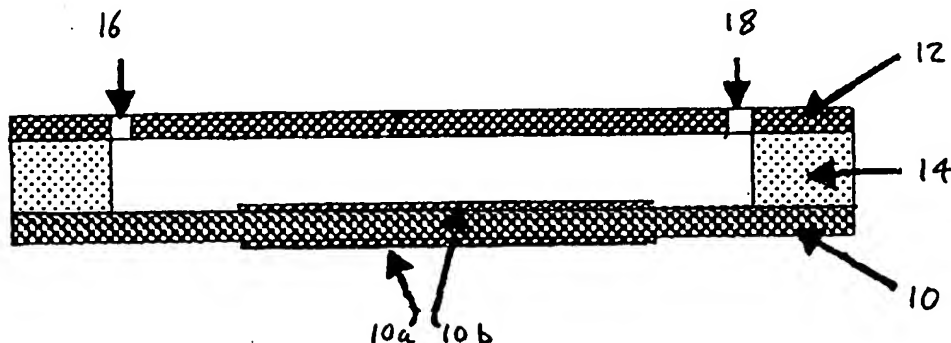
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(21) International Application Number: PCT/GB99/02384 (22) International Filing Date: 22 July 1999 (22.07.99) (30) Priority Data: 9815919.7 22 July 1998 (22.07.98) GB (71) Applicant (for all designated States except US): MSTB MICROSENSORS IN SPACE AND TERRESTRIAL BIOLOGY LIMITED [GB/GB]; 14 Quarry Road, Swansea SA5 9DJ (GB). (72) Inventors; and (75) Inventors/Applicants (for US only): CEFAI, Joseph [GB/GB]; 14 Quarry Road, Swansea SA5 9DJ (GB). BARROW, David, Anthony [GB/GB]; 65 Newfoundland Road, Gabalfa, Cardiff CF4 3LB (GB). COAKLEY, William, Terence [GB/GB]; 20 Windermere Avenue, Cardiff CF2 5PX (GB). HAWKES, Jeremy, John [GB/GB]; 8 Ladysmith Road, Panylan, Cardiff CF2 5DT (GB). (74) Agent: GIBSON, Stewart, Harry; Urquhart-Dykes & Lord, Three Trinity Court, 21-27 Newport Road, Cardiff CF2 1AA (GB).		(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

(54) Title: CONCENTRATION OF PARTICLES IN A FLUID WITHIN AN ACOUSTIC STANDING WAVE FIELD

**(57) Abstract**

A device for performing the manipulation of particles suspended in a fluid, comprises a chamber forming a duct for the flow of the fluid, and an acoustic transducer (10) and a reflector (12) for establishing an acoustic standing wave field across the width of the duct: the spacing between the transducer and reflector is 300 microns or less. With such a small spacing, the device is particularly effective at concentrating the particles and lower operating voltages are required.

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CONCENTRATION OF PARTICLES IN A FLUID WITHIN AN ACOUSTIC STANDING WAVE FIELD

The present invention relates to a device for performing the manipulation of particles suspended in a fluid, using an acoustic standing wave field.

When particles suspended in a fluid are subjected to an
5 acoustic standing wave field, the particles displace to the location of the standing wave nodes, the effectiveness of this process varying with the relative densities and compressibilities of the particles of the suspending fluid. A number of techniques have been proposed, using this
10 phenomenon, to separate particles from a liquid or other fluid. Typically, the fluid is caused to flow through a duct in which an acoustic standing wave field is established, transverse to the length of the duct. The particles accordingly displace to form a series of parallel bands: a number of outlet passages
15 may be provided to lead the individual bands of particles away from the main flow duct. Because there are engineering difficulties involved in providing an array of narrow outlet passages to collect the particle bands, the tendency is to operate at relatively low frequencies so that the wavelength
20 of the standing wave field is sufficiently large to provide an adequate spacing (half wavelength spacing) between the particle bands.

The primary acoustic force on a single particle in an acoustic standing wave field is proportional to the operating
25 frequency. Also the distance which a particle needs to move to reach a node decreases with increasing frequency, because the wavelength is smaller and hence the spacing between nodes is smaller. It is therefore easier to concentrate particles (including biological cells) at higher operating frequencies.
30 Ultrasonic cavitation is also less likely to limit the applicable acoustic pressure at higher frequencies. However, the use of high frequencies, and therefore smaller wavelengths, increases the engineering difficulties involved in providing outlet passages for the individual particle bands. Also, in
35 cases where it is desired to observe the particle bands, this is difficult or impossible when the bands are close together.

Our International patent application PCT/GB98/01274 proposes an apparatus for alleviating the above-noted difficulties. Thus, that application discloses an apparatus which comprises a duct for the flow of the fluid in which
5 particles are suspended, and means for establishing an acoustic standing wave field across the width of the duct, in which the duct is formed with an expansion in width downstream of the standing wave field. In use of this apparatus, the particles in the flowing fluid are displaced into a series of parallel
10 bands by the acoustic standing wave field. The particles remain in these bands as the fluid flows downstream from the section in which the standing wave field is present. When the fluid reaches the expansion of the duct, the stream of fluid expands correspondingly in width and, in so doing, the bands
15 of particles are spread further apart, so increasing the spacing between adjacent bands. In passing further along the flow duct, the particle bands retain increased spacing: the bands can now either be observed, or they can be separated from the duct.

20 In the apparatus disclosed in our International patent application PCT/GB98/01274, the duct has a width of 1mm in the section where the acoustic standing wave field is established. We have now found that considerable advantages accrue by forming the duct to a substantially smaller width.

25 Therefore, in accordance with the present invention, there is provided a device for performing the manipulation of particles suspended in a fluid, the device comprising a duct for the flow of a fluid in which particles are suspended, and an acoustic transducer and a reflector for establishing an
30 acoustic standing wave field across the width of the duct, the spacing between the transducer and reflector being 300 microns or less.

The transducer and reflector may form the opposite side walls of a chamber which provides the flow duct. Instead,
35 either the transducer or reflector (or both) may be positioned externally of respective side walls of the chamber. In all cases, it will be appreciated that the width of the duct is substantially smaller than in the apparatus disclosed in our International patent application PCT/GB98/01274. Preferably

the spacing between the transducer and reflector is less than 200 microns and most preferably is as small as 100 microns.

We have found that the device of the present invention is particularly effective in concentrating the particles. Preferably a half-wavelength standing wave field is established between the transducer and reflector, such that a single band of particles is formed. We have found that a substantially lower operating voltage is required, relative to chambers of greater width, in order to concentrate the particles: also, we have found that it is an easy matter to trap the particles against the flow of the suspending fluid (regardless of the orientation of the device). Moreover, we have found that extremely small particles can be manipulated effectively: we have manipulated polystyrene latex particles of 46nm diameter but believe that particles even smaller than this can be manipulated effectively.

We also believe that the device of the present invention reduces the phenomenon of particle vortexing or streaming. This phenomenon arises because, in addition to the standing wave field, there is usually a travelling wave component which causes particles to displace from the standing wave node: there is a similar effect due to differences in temperature across the width of the flow duct. However, in the device of the present invention, there is less acoustic loss due to the smaller pathlength and therefore a smaller travelling wave component: also, any localised heat is more easily dissipated due to the increased surface-to-volume ratio of the chamber.

Preferably the device is operated at the resonant frequency of the acoustic chamber, as opposed to the resonant frequency of the acoustic transducer. The operating frequency may therefore be substantially different from the resonant frequency of the transducer. The resonant frequency of the chamber may vary according to manufacturing tolerances, and will vary depending on the particular fluid and suspended particles which are to flow through it: however, the operating frequency can be adjusted for individual devices and for individual applications.

Thus, in accordance with the present invention, there

is provided a device for performing the manipulation of particles suspended in a fluid, the device comprising an acoustic chamber providing a duct for the flow of a fluid in which particles are suspended, an acoustic transducer and a reflector for establishing an acoustic standing wave field across the width of the duct, and an alternating current power source for driving the transducer, the arrangement serving to operate at the resonant frequency (or a harmonic thereof) of the acoustic chamber.

Because the particles can be trapped easily against the fluid flow, the device may be used to hold the particles for required period of time, and release some of the particles selectively (e.g. release half and retain the other half of a trapped quantity of particles). The device may be arranged to move particle from one part of the chamber to another, e.g. by energising one transducer or section of the transducer, whilst de-energising another. Also, particles may be diverted to selective output ports of the chamber.

The device of the present invention is much more effective, the larger devices, at manipulating small particles. A large number of such devices may therefore be arranged in parallel on a fluid flow path, to accommodate a large total volume flow whilst benefitting from the enhanced ability of the individual devices to manipulate small particles.

Embodiments of the present invention will now be described by way of examples only and with reference to the accompanying drawings, in which:

FIGURE 1 is an enlarged sectional view through a particle manipulation device in accordance with this invention;

FIGURE 2 is a similar view of a modified device;

FIGURE 3 is a similar view of a second embodiment of particle manipulation device in accordance with the invention; and

FIGURE 4 is a similar view of a third embodiment of particle manipulation device in accordance with the invention.

Referring to Figure 1 of the drawings, there is shown a particle manipulation device which comprises an acoustic chamber forming a duct for the through-flow of a fluid in which particles are suspended. The device comprises a planar

acoustic transducer 10 and a planar acoustic reflector 12 forming opposite parallel side walls of the chamber, and separated by a spacer 14. Inlet and outlet ports 16 and 18 are formed through the reflector 12 adjacent opposite ends of the chamber: instead, either or both parts may be formed through the transducer 10 or through the spacer 14. The electrodes of the transducer 10 are shown at 10a, 10b on its opposite sides.

In accordance with the invention, the spacing between the transducer 10 and reflector 12 is 300 microns or less and a half-wavelength standing wave field is established between the transducer and reflector, such that a single band of particles is formed. Also, the device is operated at the resonant frequency of the chamber, not at the resonant frequency of the transducer.

As mentioned above, the device is very effective in manipulating the particles and can be used to trap the particles against the through-flow of the suspending fluid.

The electrodes 11a, 11b may be deposited onto the opposite faces of the transducer 10 in a pattern which defines the location and size of the acoustic field. The electrode material can be deposited and patterned using standard microelectronic fabrication techniques.

The reflector 12 may comprise any material which exhibits an appropriate acoustic density, including glass, metal and ceramic. The reflector may comprise a single piece of such material, or it may comprise a layer of such material deposited on a support of another material.

The spacer may be formed by depositing material onto the transducer and/or onto the reflector followed by structuring steps to form the fluid channel. Alternatively, the spacer may comprise a separate member, the transducer, reflector and spacer then being bonded together.

In the modified device shown in Figure 2, the transducer 10 is provided on one face of a planar carrier 20 which forms the side wall of the chamber, opposite the reflector 12. The transducer may be formed by deposition, onto the carrier 20, of pre-cursors of the required piezo-electric material, the deposited materials then being produced (sintered, polarised, etc) to provide the piezo-electric

properties. The material of the carrier 20 is selected for its ability to couple the acoustic energy into the chamber. Alternatively, the transducer 10 may comprise a pre-fabricated member which is affixed (e.g. by gluing or bonding) onto the carrier 20: the transducer may be embedded into a recess in the carrier surface.

Referring to Figure 3, the transducer 10 may comprise a separate member, or be carried on a separate member, positioned beyond the side wall 220 of the chamber. Referring to Figure 4, both the transducer 10 and reflector 12 comprise separate members positioned beyond the opposite side walls 20, 22 of the chamber: in this case, the acoustic chamber may be removable in sliding manner from a unit which comprises the transducer and reflector, as indicated by the arrow A. It will be appreciated that, in the devices of Figures 3 and 4, the side walls 20, 22 are of materials through which the acoustic energy is able to propagate.

Claims

- 1) A device for performing the manipulation of particles suspended in a fluid, the device comprising a duct for the flow of a fluid in which particles are suspended, and an acoustic
5 transducer and a reflector for establishing an acoustic standing wave field across the width of said duct, the spacing between the transducer and reflector being 300 microns or less.
- 2) A device as claimed in claim 1, in which said transducer and reflector form opposite side walls of a chamber
10 which provides said duct.
- 3) A device as claimed in claim 1, in which either or both of said transducer and reflector is positioned externally of respective opposite side walls of a chamber which provides said duct.
- 15 4) A device as claimed in any preceding claim, in which the spacing between said transducer and reflector is less than 200 microns.
- 5) A device as claimed in claim 4, in which the spacing between said transducer and reflector is substantially 100
20 microns.
- 6) A device as claimed in any preceding claim, arranged such that a half-wavelength standing wave field is established between said transducer and reflector whereby said particles are concentrated into a single band.
- 25 7) A device as claimed in any preceding claim, including an alternating current power source for driving said transducer, the arrangement serving to operate at a resonant frequency of a chamber which provides said duct, or at a harmonic of said resonant frequency.
- 30 8) A device as claimed in any preceding claim, arranged to move particles from one location within a chamber which

provides said duct to another location within said chamber.

9) A device as claimed in any preceding claim, arranged to divert particles to selective output ports of a chamber which provides said duct.

5 10) A device for performing the manipulation of particles suspended in a fluid, the device comprising an acoustic chamber providing a duct for the flow of a fluid in which particles are suspended, an acoustic transducer and a reflector for establishing an acoustic standing wave field across the width
10 of the duct, and an alternating current power source for driving said transducer, the arrangement serving to operate at a resonant frequency of the acoustic chamber or at a harmonic of said frequency.

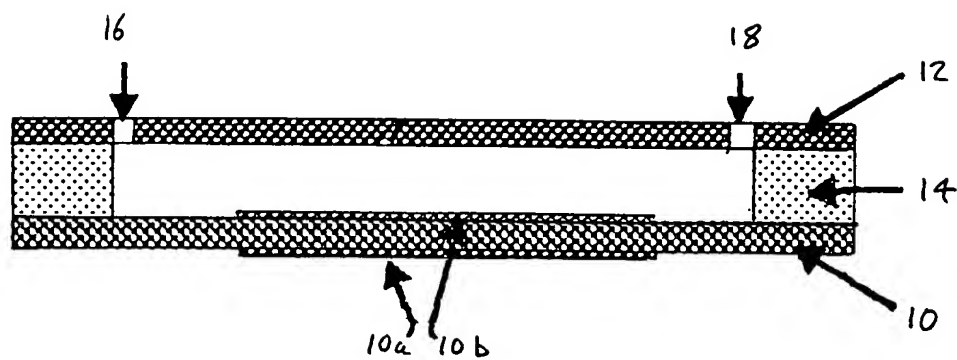


Figure 1

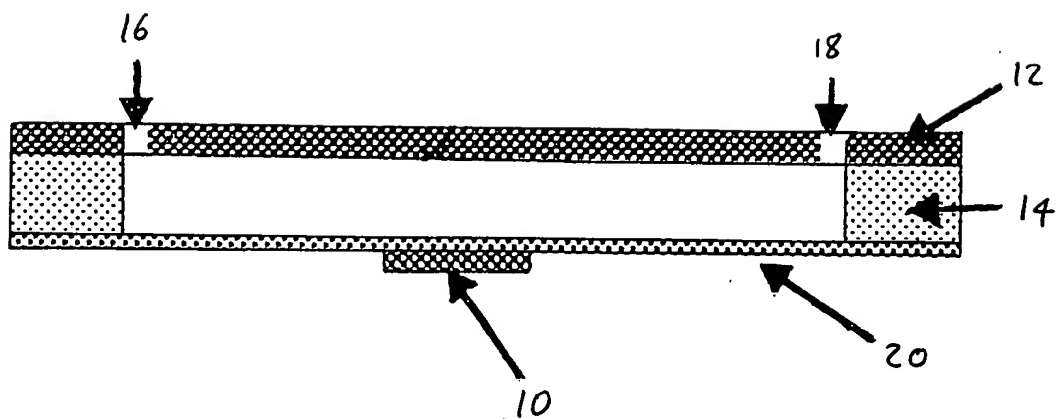


Figure 2

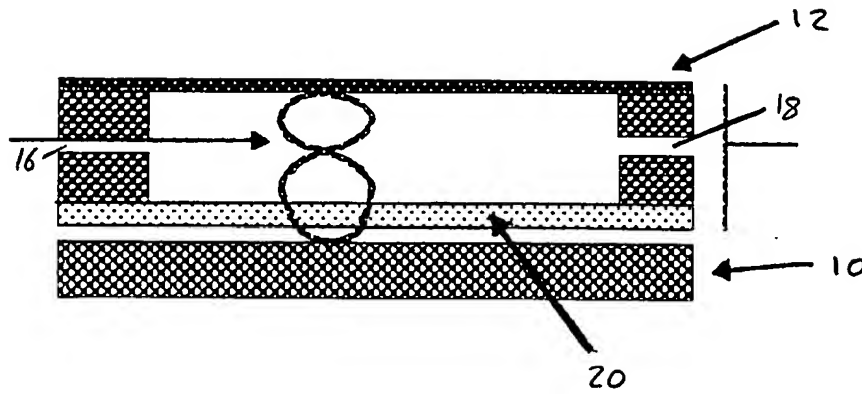


Figure 3

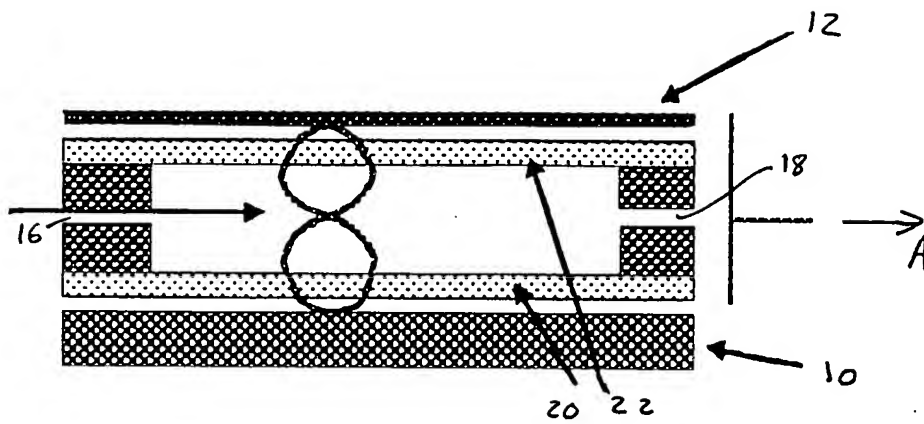


Figure 4

INTERNATIONAL SEARCH REPORT

Int'l. Application No.

PCT/GB 99/02384

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 B01D43/00 B01J8/16 G01N15/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 B01D B01J G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 018, no. 627 (P-1834), 29 November 1994 (1994-11-29) & JP 06 241977 A (HITACHI LTD;OTHERS: 01), 2 September 1994 (1994-09-02) abstract	1-6
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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